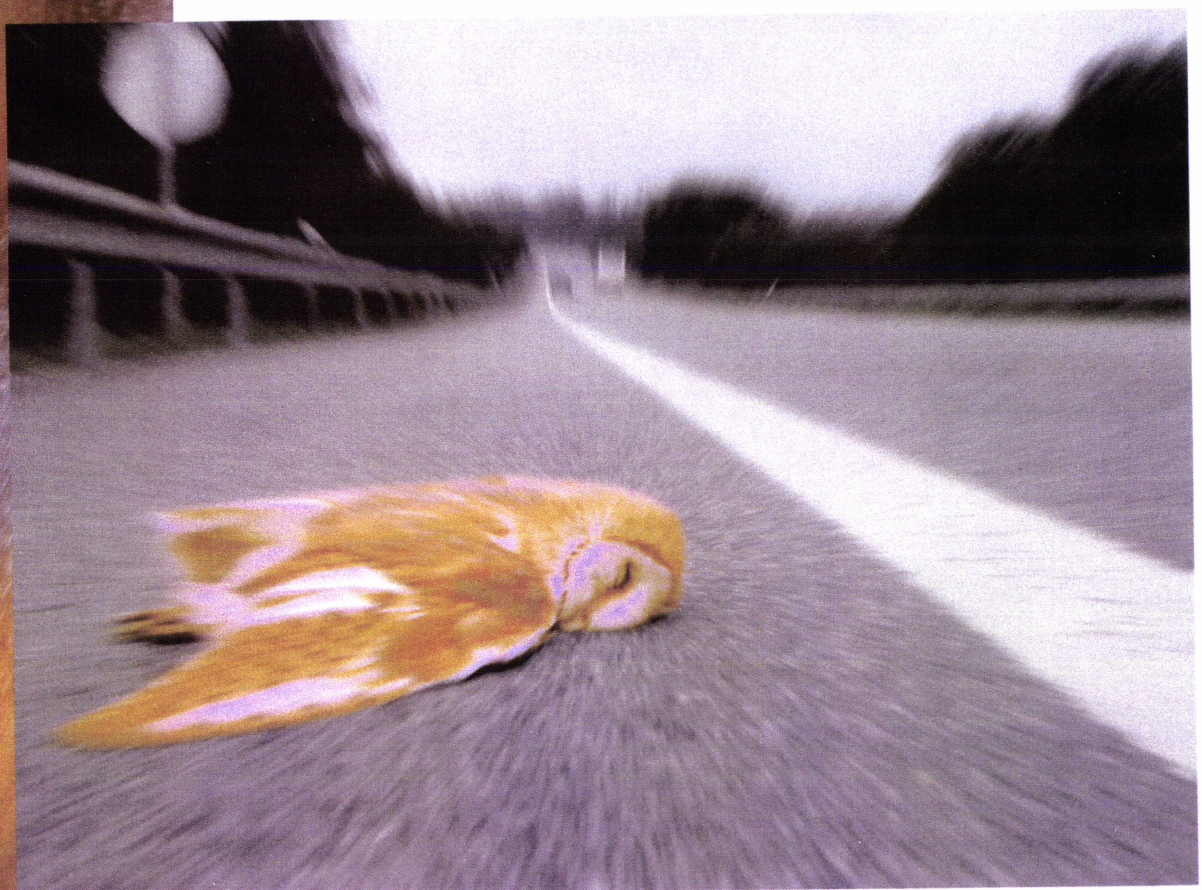
Universidade de Évora
Mestrado em Biologia da Conservação

Avaliação da Ocorrência de Pontos Negros de Mortalidade por atropelamento em Strigiformes



Dissertação realizada por
Luis Alexandre Piteira Gomes

Orientador Prof. António Mira

Esta dissertação não inclui as críticas e sugestões feitas pelo júri.

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Índice

Resumo

O atropelamento é uma das principais causas de mortalidade de Strigiformes. Como predadores de topo, a persistência das suas populações poderá encontrar-se comprometida devido á alteração da sua estrutura. Para reduzir tais efeitos, medidas de mitigação deverão ser utilizadas. A sua aplicação ao longo da totalidade das estradas não é financeiramente exequível, implicando a identificação dos locais onde essa mortalidade é mais intensa (i.e. pontos negros). Para além disso, também é necessário reconhecer quais os factores que influenciam sua distribuição, o que permitirá delinear medidas mitigadoras. O desempenho de sete métodos de identificação de pontos negros foi realizado utilizando informação de atropelos de Strigiformes recolhida sistematicamente durante dois anos, num grupo de estradas do sul de Portugal. O reconhecimento dos factores determinísticos conseguiu-se através do desenvolvimento de modelos, usando a regressão binária logística e a ENFA. Os resultados sugerem que o Kernel e o método sugerido por Malo (2004) devem ser usados para identificação dos pontos negros. O atropelo destas espécies está associado a existência de boas condições de habitat para a ocorrência das espécies, e da existência de determinadas condições que promovem a ocorrência de episódios de caça sobre a via. A determinação destes factores permitiu a definição de um conjunto de medidas mitigadoras.

Evaluation of road-fatalities hotspot distribution for Strigiformes species

Abstract

The road fatalities are among the major causes of mortality for Strigiformes species. As top predator they are, this may affect the population's perpetuity by the modification on its structure. The use of mitigation strategies must be considered, however because its application along the total length of all roads is not financially feasible, the locations where Strigiforme road-killing are more intense (i.e. road fatality hotspots) have to be identified. Aside hotspots identification, factors that influence the occurrence of such fatalities should be recognized to permit mitigation measures delineation. We use road fatality data collected from a group of south Portuguese roads during a two years period, for achieve the performance of five different hotspot identification methods. For deterministic factors recognition, binary logistic regression and ENFA modelling were applied. Our results suggest that kernel density estimation and Malo's method should be preferred to hotspot identification. The factors found as determinants of this kills are associated with the existence good habitat conditions for species occurrence, and the existence of specific conditions that promote hunting behaviour near roads. According to these factors several mitigation measures were recommended.

Introdução

O meio natural, como o conhecemos, há muito que sofre com os impactes "positivos"e "negativos" da actividade humana, sendo um bom exemplo deste facto a fragmentação que a paisagem natural tem vindo a ser alvo (Forman & Deblinger., 2000; Saunders et al., 1991), principalmente devido à construção de vias rodoviárias (Kuitunen et al., 1998; Seiler, 2001; Vos & Chardon, 1998). De uma forma geral os efeitos conhecidos destas estruturas sobre os ecossistemas podem ser agrupados por cinco grandes categorias: (1) Destruição de Habitat; (2) Poluição e Perturbação; (3) Corredor; (4) Mortalidade e (5) Barreira (Seiler, 2001).

As estradas são autênticas barreiras aos movimentos animais, sejam eles diários ou sazonais, promovendo o isolamento e impedindo o fluxo genético entre populações de diversas espécies (Carr & Fahrig, 2001; Rodriguez et al., 1996). Alguns autores atribuem a este isolamento, a extinção das populações a nível local (Saunders et al., 1991). Um dos impactes negativos mais importantes e mensuráveis que as vias rodoviárias provocam sobre as comunidades animais é a morte por atropelamento (Carr & Fahrig, 2001; Davies et al., 1987; Garnica & Robles, 1986; Malo et al., 2004; Philcox et al., 1999; Prieto et al., 1993; Rodda, 1990; Vignes, 1984).

Nas últimas décadas a morte por atropelamento perece ser o principal problema de conservação que afecta as aves de rapina nocturnas (Ordem: Strigiformes) (Fajardo et al., 2000; Frías, 1999; Hernandez, 1988; Meek et al., 2003; Newton et al., 1997; Ramsden, 2003). Dentro deste grupo, as mais afectadas pelo impacto directo das estradas são também as mais abundantes, designadamente o Mocho Galego (*Athene noctua*) e a Coruja das Torres (*Tyto alba*) (Gragera et al., 1992). Actualmente pensa-se que os indivíduos são muitas das vezes atropelados durante os voos de caça, a baixa altitude, ao tentar capturar micro mamíferos que se movimentam nas bermas das estradas, tornando-se assim vítimas dos veículos (Hill & Hockin, 1992; Nores & Moro, 1990). As baixas causadas de entre os indivíduos desta ordem relevam-se relativamente às baixas de indivíduos de outras espécies, atendendo à sua posição mais sensível como predadores de topo (Palmeirim et al., 1994), que de uma forma geral apresentam densidades populacionais mais baixas que as espécies de níveis tróficos inferiores, sendo também mais vulneráveis a mudanças no habitat (Elias et al., 1998).

A mortalidade massiva destas espécies em locais em que a taxa de natalidade não é suficiente para compensar estas perdas, pode levar à extinção das populações locais (Andrews, 1990; Fahrig et al., 1995; Gragera et al., 1992; Hels & Buchwald, 2001; Newton et al., 1991). A mortalidade de um elevado número de juvenis também compromete a existência de novos casais reprodutores, podendo determinar a regressão de tais populações (Fajardo et al., 1992).

Dado o elevado número de Strigiformes atropeladas é necessário definir estratégias que permitam mitigar o efeito de tais estruturas. Tendo em vista determinar tais estratégias é necessário conhecer quais os factores que os condicionam a ocorrência de atropelos e a forma como actuam (Clevenger et al., 2003). No entanto, a informação reunida acerca do atropelamento de aves de rapina nocturnas é escassa e inconclusiva (Fajardo, 2001; Gragera et al., 1992; Hernandez, 1988; Muntaner & Mayol, 1996), para além de identificar quais as medidas potencialmente mitigadoras desta mortalidade é essencial conhecer também quais os locais onde a mortalidade é mais intensa (i.e. *pontos negros*), pois a aplicação de tais medidas seria financeiramente incomportável para a extensão total das estradas. A selecção de pontos negros de mortalidade para aplicação de tais medidas visa garantir uma maior eficácia das mesmas.

Para atingir tais fins, face à complexidade dos factores envolvidos, o desenvolvimento de modelos preditivos da ocorrência de atropelos é uma boa ferramenta, pois permite: (1) identificar as variáveis que determinam a probabilidade de atropelo e (2) identificar os pontos negros de mortalidade (Mac Nally, 2000). Modelos preditivos semelhantes foram desenvolvidos em estudos recentes (Finder et al., 1999; Malo et al., 2004; Nielsen et al., 2003; Ramp et al., 2005; Saeki & Macdonald, 2004), no entanto nenhum deles visava exclusivamente as aves de rapina nocturnas. A necessidade de desenvolver modelos exclusivos para espécies de Strigiformes justifica-se pelo facto de partilharem características específicas, tais como tácticas de caça, padrões de dispersão de juvenis associado a elementos da paisagem (Shawyer, 1987) e período de actividade quase exclusivamente nocturno (Mikkola, 1983), que alteram o ajuste dos modelos gerais quando aplicados a estas espécies.

Muitos métodos foram desenvolvidos para identificação de pontos negros (Everett, 1974). Modelos predictivos para identificação de pontos negros implicam a utilização da informação da ocorrência de atropelos por troços de estrada (Finder et al., 1999; Malo et al., 2004; Ramp et al., 2005; Saeki & Macdonald, 2004). Outros métodos implicam a modelação dos atropelos com base em informação pontual (Clevenger et al., 2003), ou a comparação das contagens de atropelos por segmento de estrada com a distribuição de Poisson (Malo et al., 2004). Algumas considerações foram feitas acerca da utilização destes e de outros métodos na determinação de pontos negros de mortalidade (Ramp et al., 2005), no entanto desconhecem-se estudos comparativos que permitam determinar qual método traduz melhor a realidade da ocorrência de atropelos.

Neste contexto, o presente estudo pretende: (1) compreender o padrão espacial de atropelos e identificar pontos negros em três espécies de Strigiformes num conjunto de estradas do sul de Portugal; (2) determinar qual método de identificação de pontos negros apresenta melhor performance nestas situações; (3) identificar quais os factores que determinam a probabilidade de ocorrência de atropelo de Strigiformes, permitindo inferir acerca das medidas de minimização adequadas para prevenir os atropelos destas espécies e (4) desenvolver modelos preditivos que possam vir a ser usados para determinar a localização de pontos negros em estradas para as quais não exista informação de atropelos.

Os resultados do presente trabalho vão ser sujeitos a publicação sob a forma de artigo científico, intitulado "**Deterministic factors of road-fatalities hotspot distribution for nocturnal birds of prey species**".

"Deterministic factors of road-fatalities hotspot distribution for nocturnal birds of prey species"

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Abstract

The road fatalities are among the major causes of mortality for Strigiformes species. As top predator they are, this may affect the population's perpetuity by the modification on its structure. The use of mitigation strategies must be considered, however because its application along the total length of all roads is not financially feasible, the locations where Strigiforme road-killing are more intense (i.e. road fatality hotspots) have to be identified. Aside hotspots identification, factors that influence the occurrence of such fatalities should be recognized to permit mitigation measures delineation. We use road fatality data collected from a group of south Portuguese roads during a two years period, for achieve the performance of five different hotspot identification methods. For deterministic factors recognition, binary logistic regression and ENFA modelling were applied. Our results suggest that kernel density estimation and Malo's method should be preferred to hotspot identification. The factors found as determinants of this kills are associated with the existence good habitat conditions for species occurrence, and the existence of specific conditions that promote hunting behaviour near roads. According to these factors several mitigation measures were recommended.

Introduction

It is widely accepted that roads affect many aspects of ecosystems (Forman et al., 2003; Geneletti, 2003; Lodé, 2000; Seiler, 2001). Their impact on the environment includes both direct effects on the habitats destroyed during their construction, and changes in the ecosystem dynamics they run through (Forman, 1998).

These effects can be grouped into five major categories: (1) Habitat loss, (2) Disturbance and Pollution, (3) Corridor, (4) Mortality, and (5) Barrier (Seiler, 2001). Most of these effects alter the structure of wildlife populations adjacent to roads (Forman et al., 2002), by intensifying toxic environmental contamination, limiting wildlife movement, fragmenting wildlife populations, isolating animals from their mates, and leading to resource inaccessibility (Clevenger, 1996; Develey & Stouffer, 2001; Dyer et al., 2002; Forman & Alexander, 1998; Forman et al., 2003; Lodé, 2000; Meunier et al., 2000; Richardson et al., 1997; Seiler, 2001; Spellerberg, 1998).

The most visible effect of roads is the mortality caused by collisions between fauna and motor vehicles (Malo et al., 2004). The persistence of a population can be compromised, if additional non-natural mortality (i.e. road casualties) affects a significant proportion of the population, which is not compensated by higher birth rates (Andrews, 1990; Fahrig et al., 1995; Hels & Buchwald, 2001; Newton et al., 1991).

Road-kill seems to be the principal conservation issue affecting Strigiforme populations, besides other groups, over the last decades (Fajardo et al., 2000; Frías, 1999; Hernandez, 1988; Meek et al., 2003; Newton et al., 1997; Ramsden, 2003). According to some authors, it can drive the conservation status of some Strigiforme species to a situation of gravest concern (Del Hoyo et al., 1999; Fajardo & Pividal, 1994; Newton et al., 1997).

The information gathered about road casualties among nocturnal birds of prey is scarce and inconclusive, especially with respect to understanding which factors influence this mortality (Fajardo, 2001; Gragera et al., 1992; Hernandez, 1988; Muntaner & Mayol, 1996). The majority of studies suggest that these birds hunt, feed, breed and move along the road and road-sides (Fajardo et al., 1998; Meunier et al., 2000; Ramsden, 2003).

Given the extent of wildlife killed on the roads, there is a sense of urgency with respect to minimizing the number of fauna-vehicle collisions. For the purposes of reducing fauna road-kill, mitigating measures have been tested in various studies conducted world-wide. Investigators have examined the use of fences (Clevenger et al., 2001; Ludwig & Bremicker, 1983), mirrors to dissuade animals from crossing (Ujváry et al., 1998), road signs to inform drivers about the presence of animals on the road (Pojar et al., 1975), overpasses, underpasses, road-level crossings (Clevenger & Waltho, 2000; Keller, 1999) and whistles installed on vehicles (Romin & Dalton, 1992). But none of these measures has proven to be totally effective.

To take effective measures to mitigate wildlife road casualties, it is necessary to understand which factors determine their incidence, and to identify ways of influencing these factors (Clevenger et al., 2003). Because it is not financially feasible for most governments to create road-kill management strategies along the total length of all roads, it is necessary to choose locations where application of these measures will be most effective and efficient; in other words, to optimize the number of lives saved at as low a cost as possible. For such purposes, given the likely complexity of factors involved, it is best to generate a model to predict fauna-vehicle collisions, a model which: (1) identifies the variables that determine the probability of fauna-vehicle collisions, and (2) identifies mortality hotspots (i.e. segments of the road with a disproportionately high number of fatalities) (Mac Nally, 2000). Some recent studies have provided predictive models for fatality occurrence (Finder et al., 1999; Malo et al., 2004; Nielsen et al., 2003; Ramp et al., 2005; Saeki & Macdonald, 2004), but no one has focused exclusively on nocturnal birds of prey (i.e. Strigiformes).

Strigiforme species share certain characteristics that include: different hunting tactics than other predators; juvenile dispersal patterns associated with landscape structures (Shawyer, 1987); and almost exclusive nocturnal activity, thereby reducing energy efficiency (i.e. they cannot use warm air currents in flight, like diurnal birds of prey do) (Mikkola, 1983). These characteristics may alter the accuracy of prior general road-fatality model results, thereby warranting a specific model for understanding the factors that determine Strigiforme-vehicle collisions.

Keeping this *state of art* in mind, the present study was developed to achieve three main goals: (1) to understand the spatial pattern of Strigiforme-vehicle collision locations, identifying hotspots along the surveyed roads; (2) to identify the factors that influence the likelihood of Strigiforme road casualties along these roads; and then (3) to develop predictive models that can be used to identify hotspot locations for these road-kills on other roads. If the necessary care is taken, these predictive models might generate accurate, significant estimates of the impact of different roads on Strigiforme populations, and identify target areas for the application of mitigation measures (Malo et al., 2004; Ramp et al., 2005). With these aims in mind, segments of fourteen south Portuguese roads were surveyed for Strigiforme fatalities, once each fifteen days over a two-year period. The total length of road surveyed was 628 km, counting both sides of the road. The target species were the three most abundant nocturnal birds of prey in

Portugual: the Barn owl (*Tyto alba*); the Tawny Owl (*Strix aluco*) and the Little Owl (*Athene noctua*).

When non-daily surveys are conducted, some of the carcasses can be destroyed by traffic or removed by some natural or un-natural cause between surveys, such that some reported collisions absence data may be in error. This may alter the results and the accuracy of any presence-absence model. For this reason, besides generating a logistic regression model, a presence-only model was developed, using Ecological Niche Factor Analysis (ENFA).

Methods

Study area

All the surveyed roads are located in Alentejo, Southern Portugal (38°41' to 38°01' North and 8°41' to 7°40' East). These roads (hereafter termed the *surveyed road*) all are interconnected, linking two major cities, Évora and Beja, in addition to other small localities (Figure 1). They were inserted in an area where plain is the dominating topography, with altitudes ranging from 200m to 400m. The climate is Mediterranean and annual precipitation ranges from 500mm (SW) to 800mm (SO) (Rivas-Martínez, 1981).

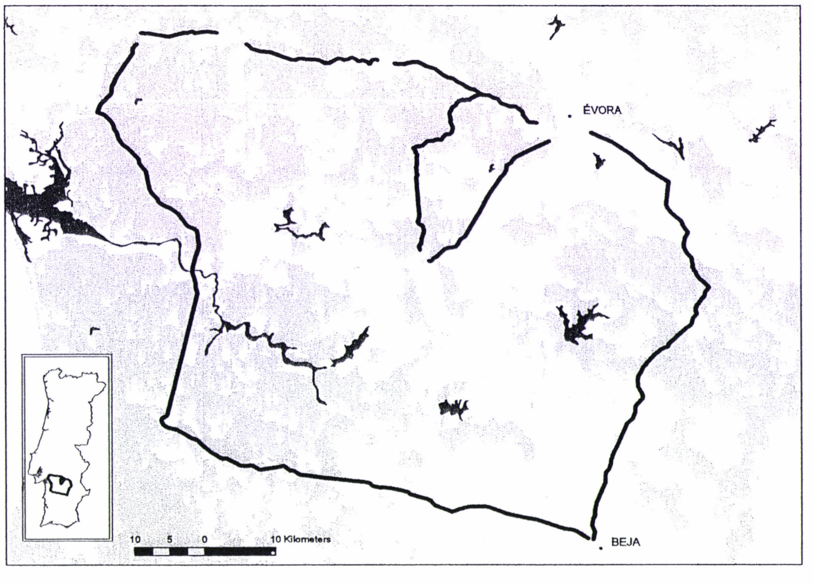

Fig 1. Map of the surveyed road. Habitats with high density of trees are indicated by light grey, and water by dark grey.

Human-altered habitats dominate the landscape, including *montado* (i.e. a traditional multiuse system that has resulted in the degradation of the original Mediterranean forest dominated by holm and/or cork oaks) accounting for 40% of the area through which these roads pass; cereal crops (28%); vines/olive orchards (13%); pine and eucalyptus production forests (11%); and urban areas (8%) (IGP, 1990).

Generally, the surveyed roads had two lanes of traffic, one in each direction and an asphalt hard shoulder, with a global mean width of 7m. Different types of fences exist along 33% of the length of the surveyed road. Sometimes, along one or both road-sides, trees form small corridors along the road. In addition, crossing or in the vicinity of the surveyed road were 14 railroads, 32 storm drains, 153 water sheds, and 196 secondary roads. The length of all surveyed segments and traffic volume, are exhibited in Table 1.

Table 1. Information about the surveyed road segments.

Surveyed segments roads	Surveyed length	Mean traffic volume (vehicles/day)
IP2	40 Km	5920
IC1	16 Km	---
EN2	16 Km	---
EN4	31 Km	8084
EN5	33 Km	9361
EN10	12 Km	8276
EN18	34 Km	8845
EN114	23 Km	13252
EN120	19 Km	---
EN121	22 Km	6508
EN257	4 Km	---
EN259	27 Km	5389
EN370	15 Km	---
EN380	22 Km	5944
Total	**314 Km**	---

The traffic volume data reefers to summer months of 2001, and was supplied by Instituto de Estradas de Portugal.
-- means lack of data

Data collection

Mortality survey

Strigiforme fatalities were counted once each fifteen days, over a two-year period, between July 2003 and July 2005. The survey was conducted by one observer traveling at 30km/h, driving along the road's hard shoulder. When a killed animal was found, the species was identified, and the location was recorded using a GPS device. To avoid double-counting, carcasses were removed from the road.

Variable acquisition

Twenty-seven variables were considered for inclusion in the models, factors reported to be meaningful to Strigiforme fatality incidence by previous investigators (Clevenger et al., 2003; Fajardo, 2001; Hernandez, 1988; Marques, 1994; Massemin & Zorn, 1998; Meunier et al., 2000; Mikkola, 1983; Petty, 1989). Table 2 presents a summary explanation about each variable, its structure, and other important features.

All the roads were subdivided into 500m segments, and each segment was characterized in terms of each variable. Some variables characterize the area through which the segment passes, defined by a buffer of 250m around the segment (Table 2). For some variables, like TDIS2S and WIDTHR a mean value was used; for others, like CTRRIG , CTRLEF, RDFENC and TREECO the most representative feature was registered. With respect to the variables DMINLO and WBDIST, the distance considered is relative to the center of the characterized segment.

The data used to calculate the MEAHEI, MEASLP and DMINLO variables were provided by the Portuguese National Environmental Centre (CNA, 1983). The GIS software used was Arcview GIS 3.2 ® (ESRI, 1999) and ArcGis 9 ® (ESRI, 2004).

Table 2. Variables, their description, units, code and source.

Variable	CODE	Description		Unit	Source
lean height	MEAHEI	Road mean height		Meters	CNA (1983)
lean slope	MEASLP	Road mean slope		Meters	Computed by Spatial Analyst (Arcview®3.2)
linimum distance to localities	DMINLO	Minimum distance to localities		Meters	CNA (1983)
rea of holm Montado	MONAZI	Porportion of Montado of holm		Percentage	Field - 250m buffer arround the road segments
rea of cork oaks Montado	MONSOB	Porportion of Montado of cork oaks		Percentage	Field - 250m buffer arround the road segments
rea of Mixed Montado	MONMIS	Porportion of mixed species Montado		Percentage	Field - 250m buffer arround the road segments
rea of Shrubland	SHRLND	Porportion of Shrubland		Percentage	Field - 250m buffer arround the road segments
rea of Cereal Crops	CERCRO	Porportion of Cereal Crops		Percentage	Field - 250m buffer arround the road segments
rea of Pine plantations	PINEPL	Porportion of Pine plantations		Percentage	Field - 250m buffer arround the road segments
rea of Eucalyptus sp. plantatior	EUCAPL	Porportion of Eucalyptus sp. plantations		Percentage	Field - 250m buffer arround the road segments
rea of Orchads	ORCHPL	Porportion of Orchads		Percentage	Field - 250m buffer arround the road segments
rea of Horticulture lands	HORTCL	Porportion of Horticulture lands		Percentage	Field - 250m buffer arround the road segments
rea of Vines plantations	VINEPL	Porportion of Vines plantations		Percentage	Field - 250m buffer arround the road segments
rea of Olive Orchads	OLIORC	Porportion of Olive Orchads		Percentage	Field - 250m buffer arround the road segments
rea of Urban area	URBARE	Porportion of Urban area		Percentage	Field - 250m buffer arround the road segments
rea of Ripicule Vegetation	VEGRIP	Porportion of Ripicule Vegetation		Percentage	Field - 250m buffer arround the road segments
rea of Rice Crops	RICCRO	Porportion of Rice Crops		Percentage	Field - 250m buffer arround the road segments
ft road-side contrast	CTRLEF	Type of contrast left road-side vs. adjacent area	(- 3) open area vs. closed area	-	Field - 250m buffer arround the road segments
			(- 2) woodland vs. closed area	-	
			(- 1) shrubland vs. closed area	-	
ght road-side contrast	CTRRIG	Type of contrast right road-side vs. adjacent area	(0) without contrast	-	Field - 250m buffer arround the road segments
			(1) woodland vs. open area	-	
			(2) shrubland vs. open area	-	
			(3) woodland and shrubland vs. open area	-	
idth	WIDTHR	Road mean width		Meters	Field
ope Diversity	SLPDIV	Number of differente slopes		-	Field
pography	RDTOPO	Road topography	(1)	-	Field
			(2)	-	Field
			(3)	-	Field
			(4)	-	Field
			(5)	-	Field
			(6)	-	Field
			(7)	-	Field
lfectos	REFLCT	Presence (1) / Absence (0) of road reflectors		-	Field
near structures	LSTYPE	Type of linear structures	(0) absence of these structures	-	Field - 250m buffer arround the road segments
			(1) watershed	-	
			(2) storm drains	-	
			(3) railway	-	
pe of Fences	RDFENC	Type of fences	(0) absence of these structures	-	Field
			(1) barbed wire	-	
			(2) broad net	-	
			(3) progressive net	-	
			(4) tight net	-	
			(5) wall	-	
ee corridor	TREECO	Presence at one side (1) / Presence at two sides (2) / Absence (0) of tree corridor along the road		-	Field
pe of Water Bodies	WBTYPE	Type of Water Bodies	(0) absence of these structures	-	Field - 250m buffer arround the road segments
			(1) temporary water bodies	-	
			(2) permanent water bodies	-	
			(3) dam	-	
istance to Water Bodies	WBDIST	Distance from road segment to water bodies		Meters	Field
istance tree 2 sides	TDIS2S	Distance between the trees of the two sides of the road	(0) absence of trees	-	Field
			(1) 10-25 meters	-	
			(2) 25-40 meters	-	
			(3) 40-60 meters	-	
			(4) +60 meters	-	
ees density	TDENSI	Percentage of road-side area ocupied by trees	(0) 0%	-	Field - 250m buffer arround the road segments
			(1) 0-10%	-	
			(2) 10-30%	-	
			(3) 30-50%	-	
			(4) 50-70%	-	
			(5) + 70%	-	
ifference of tree density	DDIFDE	Degree of trees density between two sides of road	Small degree of diference (0) to high degree of diference (5)	-	Field - 250m buffer arround the road segments
nces Density	DENFEN	Percentage of road lenght with fences		Percentage	Field
ires and Post Density	DENWPO	Percentage of road lenght with electrical wires and posts		Percentage	Field

Statistical analysis

Spatial analysis in search of fatality clustering

In order to identify global clustering in the spatial arrangement of Strigifome fatalities, Moran's I and Geary's C statistic were calculated for each species' fatality dataset. Both indices compare the value of one variable, that represents the number of fatalities, at one determined location with the same value across all other locations, using for that comparison the distance between locations (Anselin, 1992). In this work, the number of fatalities in each 500m segment was associated with the center of the same segment. All counted fatalities were restricted to the road, so distance measurements were obtained using the distance along the road "network", despite the direct distance. For these calculations, Crimestat® III software was used (Levine, 2004a).

The degree of clustering was investigated using an adaptation of Ripley's K-function, the network K-function (Okabe & Yamada, 2001). Ripley's K-function describes the clustering of data over different spatial scales, by calculating the average number of points within a determinate distance, *d*, from each point in the dataset, then dividing it by the overall study area to give K(*d*). This process is repeated for increasing distances (O'Sullivan & Unwin, 2003). The Okabe & Yamada (2001) adaptation modifies this statistic to work with distances along a network.

In order to calculate the network K-function for fatalities among the three Strigiforme species, an ArcGis extension – Sanet 2.0 (Okabe et al., 2003) was used. The values of the network K-function for observed data then had to be compared with an approximation of expected values of network K-function for a random situation, which was generated by 1000 Monte Carlo simulations. For both the observed and expected situations, the incremental distance used for K-function value calculations was 500m.

The results were modified to show the incremental value of K for each additional distance, and the total was standardised to allow for comparisons between each species (Ramp et al., 2005). For a better understanding of this measure, the *L*-statistic was calculated, as the difference between the observed and expected K-function values. With the L-statistic, positive values signify clustering in that scale, and negative values signify dispersion (Ramp et al., 2005).

Hotspot determination

There literally are dozens of different statistical techniques designed to identify 'hot spots' (Everett, 1974). To identify fatality hotspot locations, three different methods were used: (1) kernel density estimation; (2) nearest neighbour hierarchical clustering (NNHC); and (3) comparing fatality occurrences within a Poisson distribution (Malo et al., 2004).

Kernel estimation, a density technique, identifies clusters by searching for dense concentrations of fatalities (Gitman & Levine, 1970). What this does is place a smooth and symmetrical kernel function over each point, estimating a density distribution by summing the individual kernel functions for all the locations that produce a smooth cumulative density function (Levine, 2004b). The width of the kernel function (i.e. the area of influence of each kernel function, or bandwidth) chosen for the present work was 2000m for all species, making the estimation produced for all the species comparable. The choice of bandwidth size was made taking into account the reasonable scale at which mitigation measures might be taken (Ramp et al., 2005). The larger the bandwidth, the smoother the resulting cumulative density function (Gattrell et al., 1996). The kernel estimation for each species' fatalities was generated using Spatial Analyst toolbox for ArcGis®.

Nearest Neighbour Hierarchical Clustering (NNHC) is a method that identifies groups of points, based upon nearest-neighbour method criteria (Levine, 2004b). Consequently, this method defines a threshold distance, and compares that to the distances for all pairs of points (Levine, 2004b). To incorporate points in first-order clusters, the selected points have to be closer to one or more other points than the threshold distance. Afterwards, this method grouped these clusters with other clusters (second-order) by means of the same criteria, and this process was repeated until all points were grouped into one big cluster. The search for fatality hotspots, for all target species, was focused on point clustering (first-order clusters), discarding all the additional information provided by this method. The threshold distance chosen was the expected random linear nearest-neighbour distance for first-order nearest neighbours, and is calculated by

$$\text{Ld (random)} = 0{,}5\left[\frac{L}{N-1}\right]$$

where L is the total length of the road network and N is the total number of points (Hammond & McCullagh, 1978). In this context, the threshold distance was calculated for each species, using the total number of fatalities recorded for that species as N and the total length of the road as L. Another criteria that can be selected is the minimum number of points that can be included in one cluster, but any choice made, besides being arbitrary, is very difficult to justify. Hence, it was decided not to use this kind of limitation.

The last method used to investigate the locations of fatality hotspots involved comparing the spatial pattern of fatality occurrences with that expected in a random situation, in which case the likelihood of collisions for each road segment exhibits a Poisson distribution (Malo et al., 2004), hereafter referred as *Malo's method.* In this last situation, for segments of 500m, the probability of having x number of fatalities is given by

$$p(x) = \frac{\lambda^x}{\left(x!e^{\lambda}\right)}$$

where λ is the mean number of fatalities for 500m road segments (i.e. number of fatalities on all the roads divided by the total number of 500m segments). With the simple application of this equation, it was possible to determine the number of fatalities for 500m segments, above which the probability is approximately less than 2%, referred next as the *0,98 Threshold.* The suggests that high fatality rates should be distributed randomly along the road, and their aggregation in consecutive sections is very unlikely (Malo et al., 2004). Therefore, two or more contiguous 500m road segments with a number of fatalities above the *0,98 Threshold* were defined as hotspot segments.

Both the accuracy and applicability of all these methods used to identify fatality hotspots will be discussed further.

Modelling the fatalities

BLR - Binary logistic regression

A model was developed for each species, using as the dependent variable the presence/absence of fatalities along 500m road segments. Absences were defined as segments where there were no recorded fatalities. The variables described for 500m segments were used as independent variables. The number of segments assigned the value of *absence* was higher than the number of segments assigned the value of *presence*. When this happens, the logistic regression within the function's domain is not symmetrical, but rather deviates towards the extreme that presents a higher number of segments (Barbosa et al., 2003). In this situation, in ecological studies, it is assumed that there is a difference between the logistic function and a species' response to the environmental conditions (Rojas et al., 2001). The same kind of difference happens between the logistic function and fatality occurrences as an effect of the independent variables. In this study, in order to eliminate that problem, a number of segments with the absence value, corresponding to the number of segments where presence was recorded, randomly were selected for analysis, eliminating the rest of the segments with the same value.

In order to choose the independent variables that would be used in multivariate analysis, Spearman rank correlation coefficients (r) were calculated. For pairs of variables with a correlation coefficient higher than 0,7 – meaning high collinearity (Clevenger et al., 2003; Tabachnik & Fidell, 1996) - only the more biologically-meaningful variable was retained for further analysis.

As a first-step for model building, as suggested by Hosmer & Lemeshow (2000), univariate logistic regression models were constructed and tested for each independent variable. The variables with a significant likelihood-ratio at the 0,25 level were retained for multivariate analysis (Hosmer & Lemeshow, 2000).

Multivariate logistic regression was conducted, using all the selected variables, using the backward-stepwise selection method, with a 0,05 p-value threshold for entry and a 0,1 p-value threshold for removal (Pereira, 1996). The backward-stepwise variable selection method was chosen because (1) stepwise methods are the best option for exploratory work (Field, 2000; Menard, 1995); and (2) backward-stepwise selection is less likely than forward-stepwise selection to exclude independent variables involved in suppressor effects – therefore being at lower risk for generating type II error (Field, 2000). The resulting models, hereafter, will be called *environmental models.*

Because spatial autocorrelation was expected, the environmental models were converted into *autologistic models* (Augustin et al., 1998), by the inclusion of an *autologistic term* (*autocovariate*; Augustin et al., 1998) as a new variable. This term gives a response at one location as a function of the responses at neighbourhood sites (Augustin et al., 1998), thereby taking into account the possible spatial autocorrelation of the dependent variable values. The calculated autologistic term is the same suggested by (Knapp et al., 2003), and for the present study is given by

$$\sum_{j \neq i} w_{ij} \cdot y_j$$

where w_{ij} is the weighted distance (meters) between the 500m road segment i center and the center of the neighbour segment j, and y_j is equal to 1 if fatalities are present in segment j and 0 if they not. The weight distance was calculated by

$$\frac{d_{ij}^{-1/2}}{\sum_{j \neq i} d_{ij}^{-1/2}}$$

where d_{ij} is the distance (meters) between the 500m road segment i center and the center of the neighbour segment j.

The performance of resulting models (i.e. environmental and autologistic models) was estimated by means of Pearson's Chi-square test, the Phi coefficient and examining the area under the ROC curve (Receiver Operating Characteristics) – AUC (Hosmer & Lemeshow, 2000; Manel et al., 2001; Sokal & Rohlf, 1995). The area under the curve (AUC) reflects the proportion of correct and incorrect classification predictions over a range of probability thresholds (Boyce et al., 2002). The threshold used for AUC, above which the model is deemed to have good fit, was 0,7 (Manel et al., 2001). The *Jackknife* procedure was used to model validation, which consists of creating as many models as the number of cases, excluding one case at a time (Guisan & Zimmermann, 2000). The AUC also was used to evaluate the adjustment of Jackknife predictions to observed data. Also, the correct classification rate was obtained by calculating contingency tables.

For each one of the species, the performance measures permitted selection of the best model (i.e. environmental or autologistic models) for further procedures. The necessity of including a new variable in the model, like the autologistic term, is justified by the absence of any explanation for any spatial autocorrelation observed in the original set of variables (Odlund, 1988). So, if inclusion of the autologistic term does not improve model performance, this signifies that autocorrelation already is explained by the variables in the environmental model.

The coefficients derived from the selected models were applied to all 500m road segments, to produce the distribution of fatality occurrence probabilities. In order to identify the fatality hotspots predicted by the models, the 90^{th} percentile of probability values were labelled.

The analysis was carried out using the software package SPSS® 13.0 (SPSS, 2004).

ENFA – Ecological Niche Factor Analysis

In road fatality studies, as in ecological studies, accurate absence data are difficult to obtain; consequently, a modelling method that uses presence-only data must produce unbiased predictions of fatality hotspots. ENFA modelling is a presence-only method, identical to factor analysis, which compares a species' distribution in the ecological space (i.e. in the ecological variables) with the distribution of all sets of cells in the study area, producing suitability functions, and obtaining a number of uncorrelated factors that reflect the main environmental gradients within the study area (Hirzel et al., 2002a). This comparison leads to the determination of a multivariate niche occupied by the species, and it can be quantified by means of a *marginality* index and a *specialization* index (Hirzel et al., 2002a).

Through ENFA analysis, a value for marginality and another for tolerance were achieved. The first explains how the species mean differs from the global mean, and ranges from 0 to 1, '0' meaning that a species exists in the average conditions for all the study area and '1' meaning that the species tends to live in extreme conditions. The second term is the inverse of specialization, and explains how low the species' variance is compared to global variance. It likewise ranges from 0 to 1, '0' meaning that the species tends to live in a very narrow range of conditions and '1' that the species is not particularly restrictive in its living environment (Hirzel et al., 2002a). ENFA also produces a group of factors that explain species marginality and specialization. The first factor obtained with ENFA explains 100% of the marginality and some part of the specialization; the remaining level of specialization is explained by other factors. The amount of specialization explained by each one of the factors is represented by eigenvalues. The higher the absolute value of the coefficients attributed to each variable on the first factor, the further the species departs from the mean available habitat regarding the corresponding variable (Hirzel et al., 2002a). The positive and negative coefficient signs reflect whether the species prefers values that are higher than the study area mean or lower, respectively. For variable coefficients for the remain factors, only absolute values matter, so the higher these values are, the more restricted the range of the species with respect to the corresponding variable (Hirzel et al., 2002a).

Obviously, in this study the *niche* refers to the subset of cells in the ecogeographical space (relative to all the surveyed segments of road) where each one of the species fatalities has a reasonable probability of occurring. Interpreting ENFA results must take this concept into account. ENFA modelling was conducted using the Biomapper package 3.1 (Hirzel et al., 2002b). From the different algorithms that Biomapper had to use to build suitability maps for ENFA analysis, the geometric mean algorithm was chosen (Hirzel & Arlettaz, 2004). Before analysis, Box-Cox transformations of all independent variables were performed to enhance normality. For the special cases of categorical variables, a different boolean map was constructed for each category, after which a continuous surface was produced by the application of a Gaussian smoothing-using *CircAn* module. The variables that were not considered because of present constant distribution maps or nearly-bollean maps were: RICCRO; TREECO; EUCAPL; WBTYPE; RDFENC; ORCHPL; VEGRIP; and VINEPL.

The MacArthur's broken stick method was used to determine the number of factors used to calculate suitability maps (Hirzel et al., 2002a). The accuracy of the model was assessed as the area under the ROC curve (AUC).

Results

Road-fatalities surveys

Within two years of survey initiation, 593 Strigiforme fatalities were recorded. Among these, 52% were among *T.alba*, 27% among *S.aluco* and 21% among *A.noctua*. The mortality index (i.e. fatalities nº/km/year) for each of the Strigiforme species along the surveyed road was 0,49 for *T. alba*, 0,25 for *S.aluco* and 0,20 for *A.noctua*. All these contributed to the global Strigiforme mortality of 0,94 fatalities/km/year.

Along the surveyed road, traffic volume was not correlated with Stigiforme mortality (Spearman's rho (r) =0,25; p=0,516). It also was not correlated with mortality among any one of the three species (*T.alba*: r =0,133; p=0,732; *S.aluco*: r =0,333; p=0,385; *A.noctua*: r =-0,067; p=0,865;).

Strigiforme fatality clustering

As expected, significant spatial autocorrelation was identified in the distribution of fatalities for all the Strigiforme species (Table 3), meaning that the fatalities occurred in clusters, rather than being randomly distributed along the road.

Table 3. Moran's I and significance of road-fatalities locations for the three Strigiformes species

	Moran's I	Randomization significance (Z)	p-value
T.alba	0,087	21,770	0,0001
S.aluco	0,060	15,110	0,0001
A.noctua	0,076	18,850	0,0001

For *T.alba*, the *L*-statistic showed that clustering of fatalities occurred at scales up to 20km. Also for distances between 70 and 80km, fatality clustering was identified (Figure 2). As for *T.alba*, clustering at scales up to 20km was identified for *S.aluco* and *A.noctua* (Figure 2), the difference being that, for *S.aluco*, clusters also occurred punctually between 50 and 90km (Figure 2) and for *A.noctua* they occurred punctually between 20 and 130km (Figure 2).

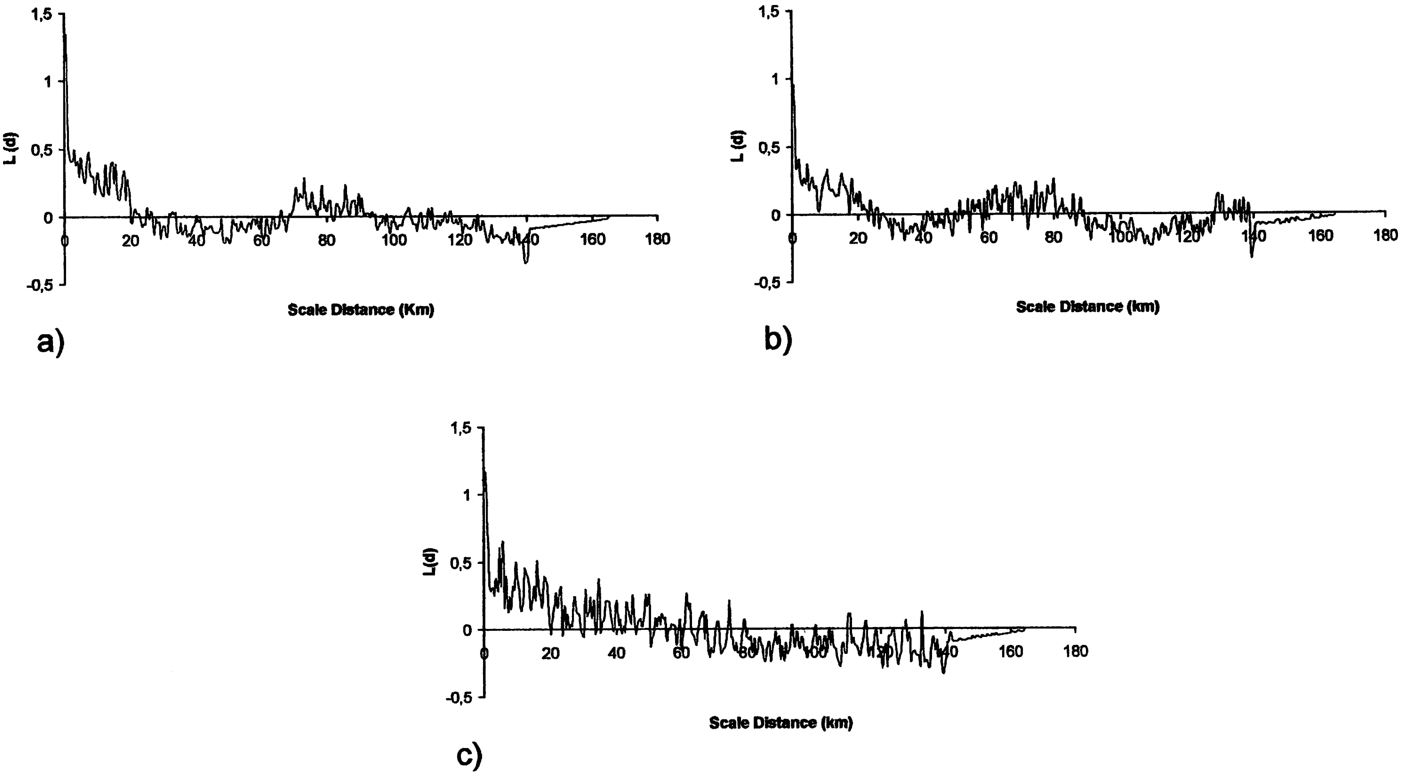

Fig 2. Graph showing *L* statistic values for the network K-function for each species. a) *T.alba*; b) *S.aluco*; c) *A.noctua.*

Hotspot identification

For *T.alba,* fatality kernel density estimates highlighted three densest hotspots (Figure 3), besides a number of small segment clusters. The over-abundance of fatalities along two segments of road, (Figure 3) each of approximately 20km length, are reflected in the *L*-statistic. The other two methods were able to identify the location of the densest fatality hotspots, but failed to show the connectivity between them as the kernel method does (Figure 4 and 5). The method that shows the most fragmented hotspot distribution was NNHC (Figure 4).

Kernel identified, for *S.aluco*, three major road segments with an over-abundance of fatalities, located in the proximity of high tree density habitats (Figure 3). In these segments, there were four dense hotspots (Figure 3). Also for *S.aluco*, the other methods revealed more conservative results, but all of them identified the same locations for the most dense hotspots (Figure 4 and 5); NNHC, however, only highlighted 7 hotspots, while *Malo's method* detected 10.

The majority of hotspots identified by kernel for *A.noctua* were located in segments adjacent to low tree density habitats (Figure 3). Two segments of road with an elevated abundance of fatalities, near Beja, may explain the clustering for scales up to 20km that was revealed by the *L*-statistic (Figure 3). One dense hotspot occurred approximately 20km from Beja (Figure 3). Both other methods generated the same results as the kernel method, similarly to the other two species (Figure 4 and 5); and, again, the *Malo's method* detected a greater number of hotspots than NNHC.

If effective minimization strategies could be applied to the identified hotspots, within a two-year period the following three measures - the relative hotspot length; the relative number of kills that were prevented; and the ratio among these measures (hereafter referred HLvsKP ratio) – would be: *T.alba* Kernel: 10%, 55%, and 5,5, respectively; *Malo's method*: 6%, 53%, 8,8; NNHC: 6%, 48%, 8,0; *S.aluco* Kernel: 10%, 51%, 5,1; *Malo's method*: 2%, 21%, 10,5; NNHC: 5%, 34%, 6,8; *A.noctua* Kernel: 10%, 60%, 6,0; *Malo's method*: 4%, 48%, 12; NNHC: 7%, 49%, 7. Note that, for these calculations, using the Kernel method, the 90th percentile of kernel density estimation values was used, and that the reference period for kills prevented was two years. For *Malo's method*, the hotspots highlighted were defined by segments with more than two fatalities for *T.alba* (*0,98 Threshold* = 0,986 probability) and for *S.aluco* (*0,98 Threshold* = 0,997 probability), and by segments with more than one fatality for *A.noctua* (*0,98 Threshold* = 0,984 probability).

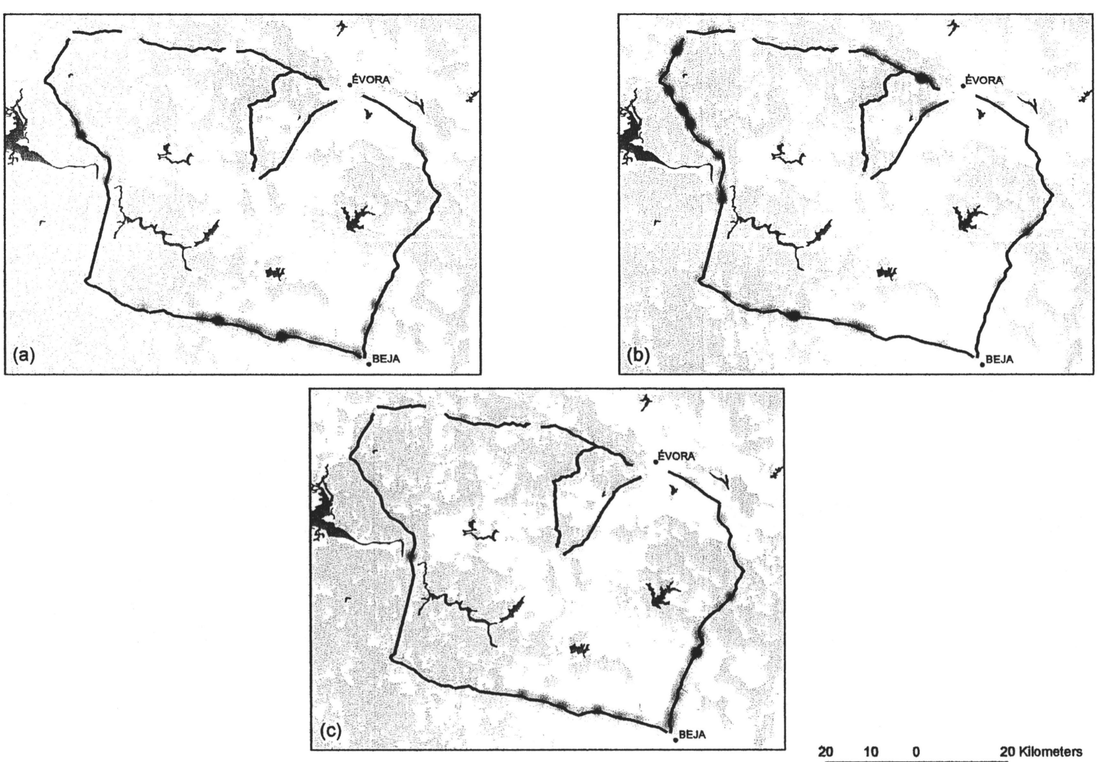

Fig 3. Maps obtained by Kernel density estimation for each species fatalities. Regions of higher density are reflected by darker shading. a) *T.alba*; b) *S.aluco*; c) *A.noctua.*

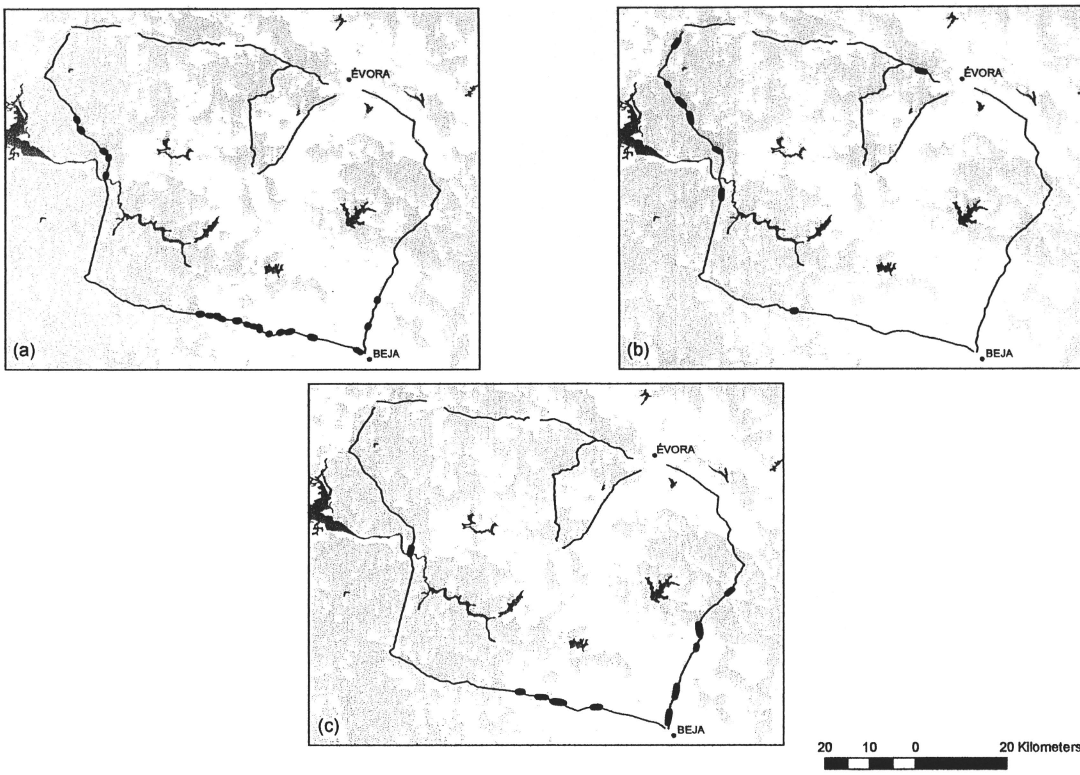

Fig 4. Maps obtained by NNHC method for each species fatalities. Identified hotspots are marked by darker shading. a) *T.alba*; b) *S.aluco*; c) *A.noctua.*

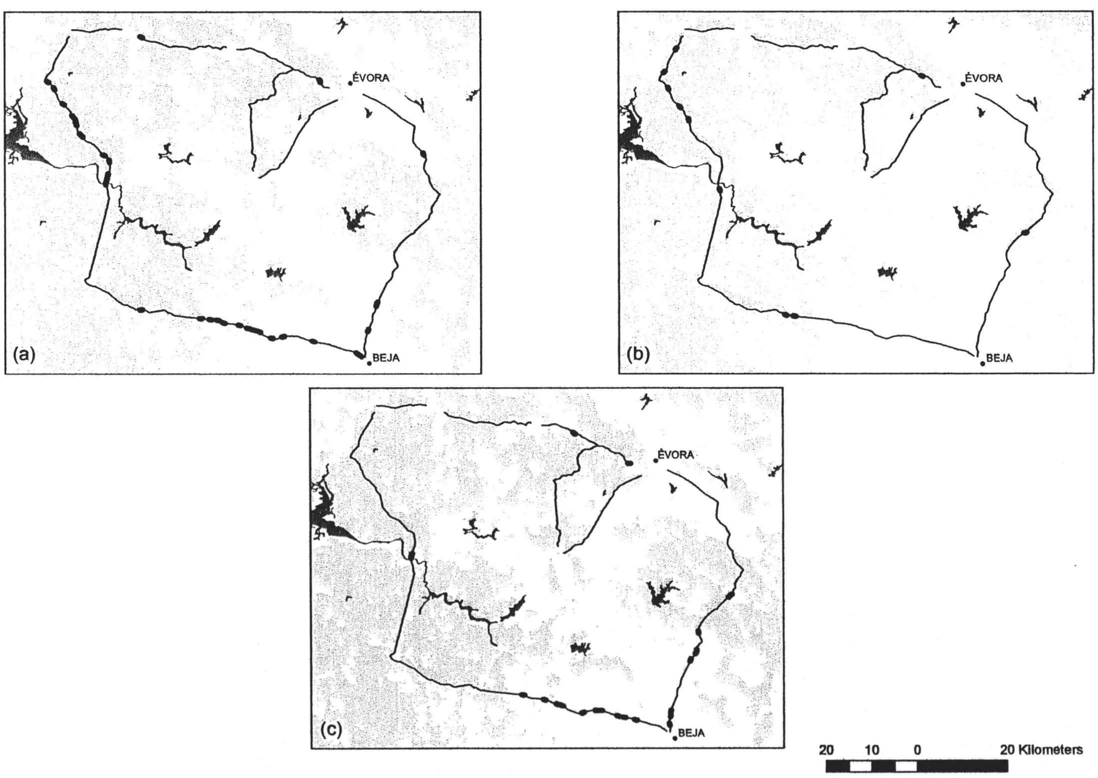

Fig. 5. Maps obtained by Malo's method for each species fatalities. Identified hotspots are marked by darker shading. a) *T.alba*; b) *S.aluco*; c) *A.noctua.*

Fatality models

BLR - Binary logistic regression

After Spearman rank correlation test and univariate logistic regression, the variables retained to perform multivariate analysis for each species fatalities were as presented in Table 4.

Table 4. Logistic regression coefficients and significance of each variable in univariate logistic regression model.

CODE		*T.alba*		*S.aluco*		*A.noctua*	
		B	**Significance**	**B**	**Significance**	**B**	**Significance**
MEAHEI		-0,004	0,006	-0,005	0,001	0,001	0,506
MEASLP		-0,387	0,039	-0,025	0,911	-0,106	0,604
DMINLO		0,000	0,292	0,000	0,527	0,000	0,000
MONAZI		0,011	0,086	0,008	0,193	-0,008	0,261
MONSOB		-0,001	0,863	0,010	0,005	-0,019	0,000
MONMIS		0,001	0,905	-0,003	0,731	-0,004	0,768
SHRLND		-0,015	0,006	0,018	0,003	-0,018	0,014
CERCRO		0,007	0,030	-0,021	0,000	0,012	0,006
PINEPL		-0,020	0,003	0,011	0,052	-0,015	0,104
EUCAPL		-0,021	0,117	0,018	0,426	-0,046	0,307
ORCHPL		0,005	0,731	0,009	0,720	0,015	0,487
HORTCL		0,031	0,368	-3,703	0,999	-0,089	0,186
VINEPL		-0,028	0,088	-0,010	0,569	0,005	0,754
OLIORC		0,004	0,437	-0,012	0,091	0,023	0,002
URBARE		-0,014	0,049	-0,007	0,411	0,006	0,391
VEGRIP		0,089	0,108	0,021	0,690	0,011	0,867
RICCRO		0,019	0,339	0,024	0,269	-0,471	1,000
CTRLEF		-22,014	1,000	-0,290	0,117	0,063	0,693
CTRRIG		20,392	0,999	-0,161	0,374	0,049	0,755
WIDTHR		0,220	0,043	0,273	0,047	0,328	0,038
SLPDIV		-0,372	0,055	0,030	0,861	0,348	0,069
RDTOPO	Type (1)	20,980	0,999	1,658	0,171	0,693	0,455
	Type (2)	21,336	0,999	1,281	0,298	-1,658	0,172
	Type (3)	21,222	0,999	0,924	0,428	-0,535	0,566
	Type (4)	20,797	0,999	1,386	0,317	-0,118	0,921
	Type (5)	21,896	0,999	1,099	0,437	-0,811	0,530
	Type (6)	22,184	0,999	1,792	0,214	-0,405	0,810
REFLCT		-0,055	0,815	-0,150	0,584	0,706	0,028
LSTYPE	(1) watershed	0,558	0,524	-3,542	0,001	-21,240	1,000
	(2) storm drains	1,173	0,193	-0,502	0,115	-21,710	1,000
	(3) railway	0,693	0,505	-	-	-20,960	1,000
RDFENC	(1) barbed wire	1,161	0,053	0,719	0,414	-1,202	0,151
	(2) broad net	0,164	0,856	1,386	0,258	-2,015	0,085
	(3) progressive net	0,829	0,198	0,613	0,501	-0,875	0,314
TREECO		1,388	0,000	20,980	0,939	0,125	0,725
WBTYPE	(1) temporary water bodies	-2,702	0,000	1,281	0,118	-1,992	0,004
	(2) permanent water bodies	-0,353	0,183	1,253	0,138	-0,844	0,010
WBDIST		0,000	0,003	0,000	0,315	0,000	0,069
TDIS2S		-0,097	0,254	-0,287	0,006	0,125	0,253
TDENSI		-0,124	0,181	0,597	0,000	-0,610	0,000
DDIFDE		0,140	0,486	0,182	0,428	-0,435	0,136
DENFEN		-0,007	0,014	-0,001	0,653	-0,006	0,099
DENWPO		0,001	0,768	-0,018	0,001	0,009	0,098

T.alba

Of the 20 variables chosen to perform multivariate analysis, eight were selected by the backward-stepwise method to comprise the environmental model (Table 5). This model was statistically-significant (chi-square = 99,029; $p<0,01$), correctly classifying 77,1% of the cases (72,8% of the presences and 78,5% of the absences). The model was adjusted to the data (Φ = 0,483, $p<0,01$; AUC = 0,817, $p<0,01$). The validation jackknife procedure results suggest that the model can be applied to our road to estimate the probability of fatality occurrence (AUC = 0,693, $p<0,01$). The autologistc model (Table 5) also was significant (chi-square = 105,747; $p<0,01$), correctly classifying 73,8% of the cases (72,8% of the presences and 74,8% of the absences). However, it appeared to better fit the data (Φ = 0,476, $p<0,01$; AUC = 0,823, $p<0,01$) than the unadjusted model. Also the validation procedure demonstrated that its estimates along the surveyed road better fit the actual data than the environmental model (AUC = 0,750, $p<0,01$). For these reasons, the autologistic model was selected to predict the location of fatality hotspots for this species.

The environmental model demonstrated that the mean altitude, percentage of pine tree habitat, percentage of urban area, presence of any kind of water body, distance between trees on the two sides of the road, and the density of trees near the road are negatively correlated with the occurrence of *T.alba* fatalities. Conversely, fatalities were positively correlated with the presence of fences and linear structures (i.e. watersheds, storm drains and railways) along the road, and the distance from bodies of water (Table 5).

S.aluco

The modelling procedure selected five variables to incorporate in the environmental model (Table). It was significant and fit the data well (chi-square = 42,799; $p<0,01$; Φ = 0,445, $p<0,01$; AUC = 0,795, $p<0,01$), correctly classifying 72,2% of the cases (75,0% of the presences and 69,4% of the absences). The association between observed and predicted cases was significant (Jackknife validation: AUC = 0,755, $p<0,01$). Again, the autologistic model (Table 5) performed better in terms of goodness of fit and model validation (Φ = 0,519, $p<0,01$; AUC = 0,815, $p<0,01$; Jackknife validation: AUC = 0,78, $p<0,01$). The adjusted model also was significant (chi-square = 58,254; $p<0,01$), but correctly identified a greater number of cases

(75,9%) than the first. As for *T.alba*, the model selected to predict the location of fatality hotspots was the one that was autologistic.

The incidence of *S.aluco* fatalities appeared to be positively correlated with the percentage of montado habitats and the density of trees proximal to the roads, while the presence of water bodies and electrical/telephone wires and posts were negatively correlated (Table 5).

A.noctua

The environmental model (Table 5) retained nine of the initial variables, all of which resulted in significant improvements versus the null model (chi-square = 63,966; $p<0,01$). The model fit was good ($\Phi = 0,547$, $p<0,01$; AUC = 0,817, $p<0,01$), but poor performance in the area under the curve only weakly validated its performance when used on the surveyed road (Jackknife validation: AUC = 0,654, $p<0,01$). The autologistic model also was significant and fit the data well (chi-square = 64,685; $p<0,01$; $\Phi = 0,537$, $p<0,01$; AUC = 0,819, $p<0,01$), but it also demonstrated only weak performance when validation was tested (Jackknife validation: AUC = 0,664, $p<0,01$). Nonetheless, the model used to predict fatality hotspots was the autologistic model.

Minimum distance to localities, the presence of water bodies near the road, the presence of fences, increasing distance between trees on the two sides of the road, and the density of trees in the immediate area were negatively correlated with *A.noctua* fatality incidence, while the presence of cereal crops in the road proximity, the presence of reflectors on the road sides, and slope diversity were positively correlated.

The maps with predicted hotspots are showed in Figure 6. Relative hotspot length, relative number of kills that were prevented if an effective minimization measure was applied, and HL vs KP ratio, again were estimated assuming two years of intervention at hotspot, and were: *T.alba* 12%, 31%, 2,6; *S.aluco* 11%, 30%, 2,7; and *A.noctua* 10%, 30%, 3. This method demonstrated the weakest performance of any of the hotspot identification methods.

Table 5. Results of multivariate logistic regression models; ß = regression coefficient, S.E. = standard error of the regression coefficients, Wald = Wald statistics, *P* = significance level.

T.alba		ß	S.E.	Wald	*P*			ß	S.E.	Wald	*P*
Environmental model						**Autologistic model**					
MEAHEI		-0,005	0,002	5,904	0,015	**MEAHEI**		-0,002	0,003	0,83	0,362
PINEPL		-0,033	0,008	15,303	<0,001	**PINEPL**		-0,025	0,009	8,351	0,004
URBARE		-0,02	0,008	6,358	0,012	**URBARE**		-0,02	0,008	6,082	0,014
				8,483	0,037					3,319	0,345
RDFENC	**1**	1,846	0,702	6,915	0,009	**RDFENC**	**1**	1,276	0,74	2,978	0,084
	2	0,576	1,03	0,313	0,576		**2**	0,565	1,032	0,3	0,584
	3	1,498	0,774	3,739	0,053		**3**	1,113	0,793	1,969	0,161
				7,742	0,052					5,848	0,119
LSTYPE	**1**	0,953	0,963	0,978	0.323	**LSTYPE**	**1**	0,532	0,978	0,296	0,587
	2	1,88	1,02	3,398	0,065		**2**	1,392	1,038	1,797	0,18
	3	0,934	1,25	0,558	0,455		**3**	0,5	1,294	0,149	0,699
				18,613	<0,001					8,855	0,012
WBTYPE	**1**	-3,231	0,749	18,61	<0,001	**WBTYPE**	**1**	-2,375	0,817	8,453	0,004
	2	-0,55	0,331	2,766	0,096		**2**	-0,53	0,332	2,547	0,11
WBDIST		$6,077*10^{-5}$	$2,5*10^{-5}$	5,869	0,015	**WBDIST**		$2,87*10^{-5}$	$2,9*10^{-5}$	1,001	0,317
TDIS2S		-0,367	0,141	6,767	0,009	**TDIS2S**		-0,216	0,152	2,023	0,155
TDENSI		-0,303	0,164	3,435	0,064	**TDENSI**		-0,161	0,174	0,857	0,355
Constant		0,017	1,436	0	0,991	*Autocovariate*		11,754	4,787	6,028	0,014
						Constant		-2,944	1,864	2,496	0,114
S.aluco		**ß**	**S.E.**	**Wald**	***P***			**ß**	**S.E.**	**Wald**	***P***
Environmental model						**Autologistic model**					
MONAZI		0,013	0,007	3,919	0,048	**MONAZI**		0,013	0,007	3,706	0,054
MONSOB		0,01	0,005	4,108	0,043	**MONSOB**		0,005	0,005	0,912	0,34
				13,336	0,001					7,814	0,02
WBTYPE	**1**	-3,953	1,1	12,916	<0,001	**WBTYPE**	**1**	-2,979	1,133	6,915	0,009
	2	-0,533	0,362	2,172	0,141		**2**	-0,575	0,381	2,277	0,131
TDENSI		0,468	0,143	10,73	0,001	**TDENSI**		0,257	0,162	2,513	0,113
DENWPO		-0,01	0,006	3,231	0,072	**DENWPO**		-0,01	0,006	3,146	0,076
Constant		-0,139	0,619	0,05	0,823	*Autocovariate*		18,203	6,308	8,328	0,004
						Constant		-2,913	1,142	6,506	0,011
A.aluco		**ß**	**S.E.**	**Wald**	***P***			**ß**	**S.E.**	**Wald**	***P***
Environmental model						**Autologistic model**					
DMINLO		$-3,15*10^{-4}$	$9*10^{-5}$	12,393	<0,001	**DMINLO**		$-3,0*10^{-4}$	$9,1*10^{-5}$	11,178	0,001
CERCRO		0,01	0,006	2,761	0,097	**CERCRO**		0,008	0,007	1,594	0,207
SLPDIV		0,52	0,277	3,516	0,061	**SLPDIV**		0,469	0,283	2,744	0,098
				7,458	0,059					4,659	0,199
RDFENC	**1**	-0,056	1,078	0,003	0,959	**RDFENC**	**1**	-0,246	1,085	0,051	0,821
	2	-2,545	1,393	3,339	0,068		**2**	-2,284	1,41	2,626	0,105
	3	-0,851	1,11	0,588	0,443		**3**	-0,974	1,107	0,775	0,379
REFLCT		1,019	0,506	4,059	0,044	**REFLCT**		0,957	0,513	3,485	0,062
				5,708	0,058					3,671	0,16
WBTYPE	**1**	-1,132	0,806	1,969	0,161	**WBTYPE**	**1**	-0,82	0,881	0,867	0,352
	2	-0,946	0,415	5,204	0,023		**2**	-0,83	0,435	3,639	0,056
TDIS2S		-0,443	0,181	5,973	0,015	**TDIS2S**		-0,379	0,196	3,735	0,053
TDENSI		-0,641	0,265	5,87	0,015	**TDENSI**		-0,542	0,289	3,518	0,061
Constant		2,774	1,401	3,92	0,048	*Autocovariate*		4,878	5,746	0,721	0,396
						Constant		1,838	1,776	1,071	0,301

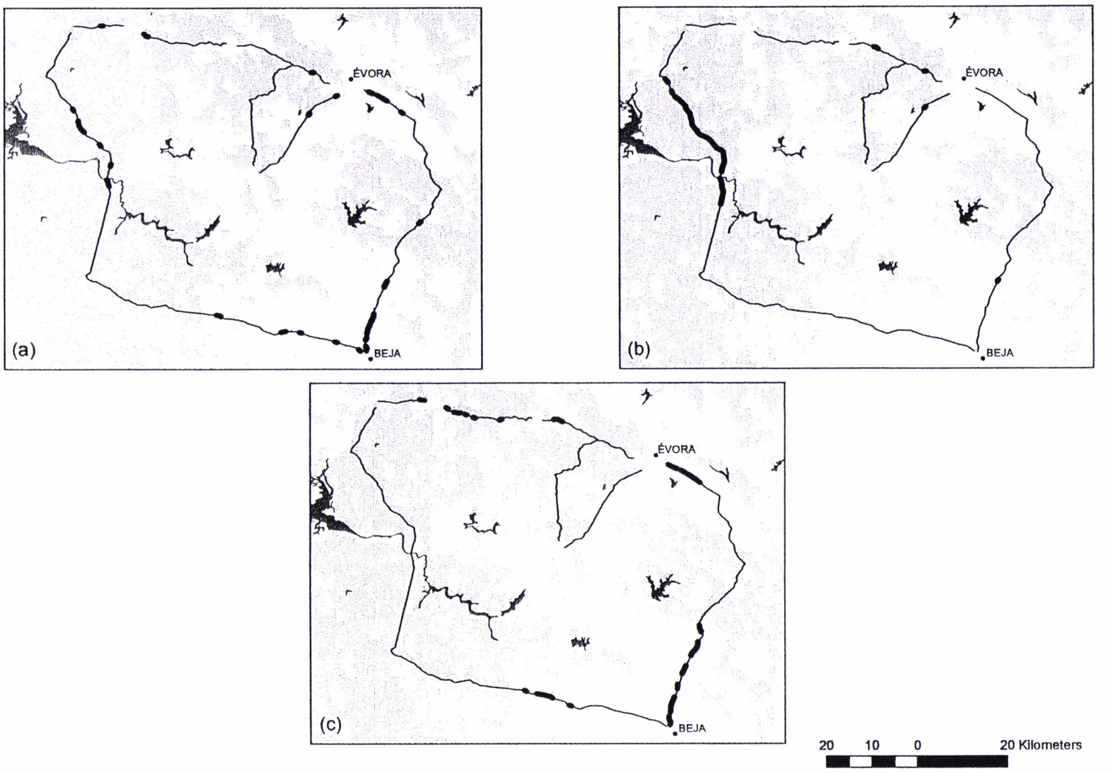

Fig. 6. Maps obtained by BLR for each species fatalities. Identified hotspots are marked by darker shading. a) *T.alba*; b) *S.aluco*; c) *A.noctua.*

ENFA – Ecological Niche Factor Analysis

T.alba

The obtained model explained 73% of all the data. Fatalities appeared to occur under conditions that were slightly different from the mean conditions along the surveyed road (Global marginality = 0,415), and under moderately specific conditions (Tolerance = 0,642). Examination of the marginality factor suggested that the variables that most significantly influence fatality rates are mean altitude, the presence of topography type 4, the road width, and the distance to water bodies (Table 6). The signal of score values demonstrated that road-kills are associated with smaller values of the first three of these variables and higher values of the last two (Table 6). Eight percent of the specialization was explained by the marginality factor, the remaining being related to road width, the presence of topography type 7, the presence of scrubland, and montado in the proximity of the road (Table 6). The model's fit was moderate (AUC = 0,634, $p<0,05$). Four factors were used to configure the hotspot location maps (Figure 7).

S.aluco

For this species, the fatalities seemed not to occur under a wide range of conditions (Tolerance = 0,656), and exhibited a moderate difference from mean conditions (Global marginality = 0,634). The model explained 81% of the data. Higher values for tree density and the proportion of pine tree habitat and lower values for mean altitude, the proportion of olive orchards, and scrub land habitats near the road were optimum conditions for fatalities (Table 6). Besides the first factor, the remaining specialization was explained by the other six factors, which are associated with slope diversity, the presence of topography types 3 and 4 near the road, and road-side versus adjacent area contrast (Table 6). The goodness of fit was moderate (AUC = 0,682, $p<0,05$). The hotspot map was configured using seven factors (Figure 7).

A.noctua

For *A.noctua*, fatalities tend to occur under very distinct conditions (Global marginality = 0,878) and in a moderate range for variables (Tolerance = 0,552). Fatalities seem to occur preferentially with smaller values for minimum distance to localities and proportion of montado habitat, and higher values for percentage of olive orchards habitats and road-side versus adjacent area contrast (Table 6). These variables only explain 12% of the specialization, the remaining associated with the different types of topography, the mean altitude, and the proportion of pine tree habitats. The amount of information explained by this model was 87%, showing good fit (AUC = 0,805, $p<0,05$). Nine factors were used to configure the fatalities hotspot map (Figure 7)

All the ENFA models explained a small amount of the specialisation relative to the first factor (i.e. marginality), which means that the variables for which fatality occurrences tend to differ from global conditions are not the same as when the model is more specific (Hirzel et al., 2004). The hotspot maps obtained using ENFA models, like the maps produced by binary logistic regression, exhibited weak performance when the relative dimensions of suggested hotspots and kills prevented over two years were calculated: (*T.alba* 10% relative length, 19% kills prevented, HLvsKP ratio = 1,9; *S.aluco* 8% relative length, 19% kills prevented, HLvsKP ratio = 2,3; *A.noctua* 9% relative length, 30% kills prevented, HLvsKP ratio = 3,3).

Table 6. Results of Ecological Niche Factor Analysis. The four most important variables in each factor, sorted by decreasing absolute values of the coefficients.

T.alba

Marginality	Specialisation		
Factor 1 (8%)	**Factor 2 (18%)**	**Factor 3 (13%)**	**Factor 4 (7%)**
MEAHEI (-0,38)	WIDTHR (-0,51)	RDTOP 7 (0,37)	MONMIS (0,38)
RDTOP 4 (-0,31)	CTRLEF (-0,33)	SHRLND (0,33)	CTRRIG (0,37)
WIDTHR (0,31)	DDIFDE (0,28)	RDTOP 4 (-0,32)	RDTOP 3 (-0,36)
WBDIST (0,31)	RDTOP 3 (0,27)	HORTCL(-0,29)	SLPDIV (-0,33)

S.aluco

Marginality	Specialisation					
Factor1 (7%)	**Factor2 (18%)**	**Factor3 (10%)**	**Factor4 (8%)**	**Factor5 (7%)**	**Factor6 (7%)**	**Factor 7 (5%)**
TDENSI (0,34)	SLPDIV (-0,53)	RDTOP 3 (-0,53)	RDTOP 4 (0,47)	CTRLEF (-0,40)	RDTOP 3(0,45)	RDTOP 3(-0,41)
PINEPL (0,33)	RDTOP 3 (-0,45)	CTRRIG (-0,32)	SLPDIV (0,43)	WBDIST (-0,34)	MONMIS (-0,40)	RDTOP 1(-0,40)
MEAHEI (-0,33)	MEAHEI (0,39)	PINEPL (-0,29)	MEAHEI (-0,41)	CTRRIG (0,34)	CTRRIG (0,37)	CERCRO (-0,40)
OLIORC (-0,28)	OLIORC (0,28)	RDTOP 5 (-0,28)	CTRLEF (-0,35)	MEAHEI (0,32)	WIDTHR (0,34)	RDTOP 6 (-0,39)

A.aluco

Marginality	Specialisation							
Factor 1 (12%)	**Factor 2 (15%)**	**Factor3 (14%)**	**Factor4 (9%)**	**Factor5 (8%)**	**Factor6 (6%)**	**Factor7 (5%)**	**Factor8 (5%)**	**Factor9 (3%)**
OLIORC (0,46)	RDTOP 3(-0,78)	MEAHEI (0,46)	RDTOP 3 (0,67)	PINEPL (0,46)	RDTOP 7 (-0,39)	RDTOP 3(0,66)	RDTOP 5 (0,45)	RDTOP 3 (0,57)
DMINLO (-0,35)	RDTOP 1 (-0,38)	RDTOP 1(0,35)	RDTOP 1 (0,35)	RDTOP 3 (0,42)	RDTOP 3(0,34)	SLPDIV (0,25)	MONSOB (0,37)	RDTOP 2 (0,38)
CTRRIG (0,29)	RDTOP 5 (-0,27)	SLPDIV (-0,32)	MEAHEI (0,28)	SLPDIV (0,39)	DDIFDE (0,33)	RDTOP 6 (0,25)	PINEPL (-0,33)	RDTOP 7 (0,31)
CTRLEF (0,27)	RDTOP 7 (-0,22)	RDTOP 7 (-0,29)	CTRLEF (-0,27)	WBDIST (-0,32)	PINEPL (-0,29)	DMINLO (0,24)	RDTOP 3 (0,27)	MEAHEI (-0,30)

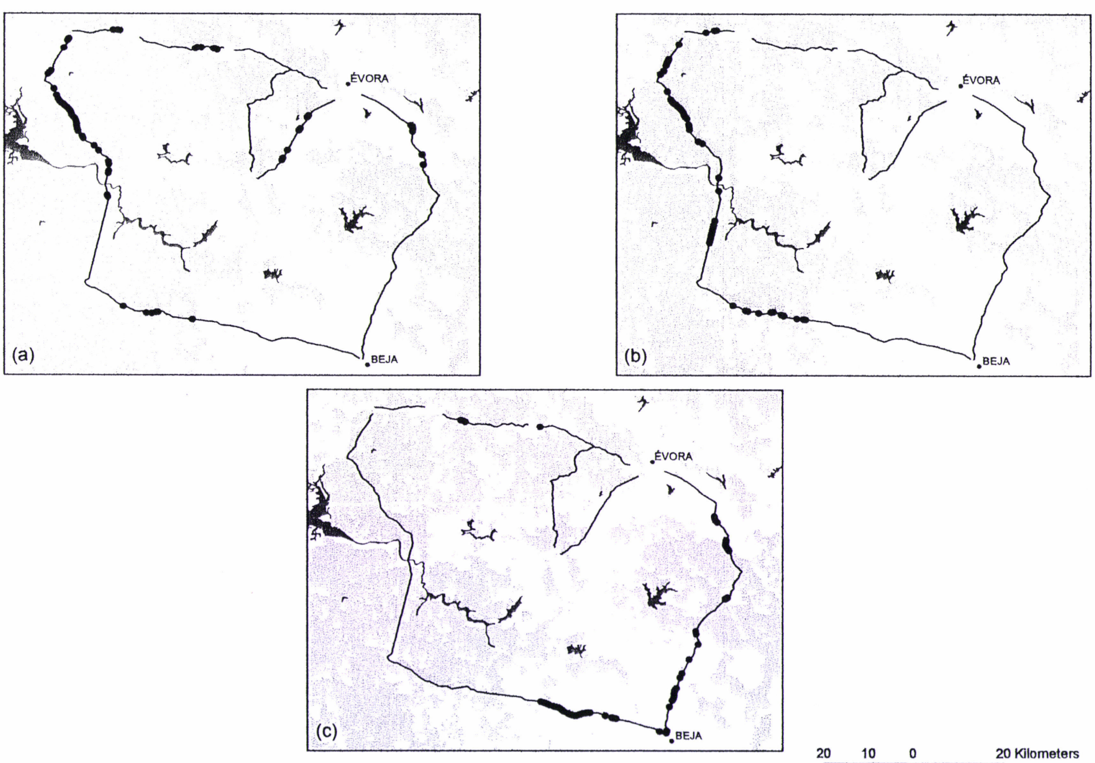

Fig. 7. Maps obtained by ENFA for each species fatalities. Identified hotspots are marked by darker shading. a) *T.alba*; b) *S.aluco*; c) *A.noctua.*

Discussion

Road collisions actually are considered to be the major cause of mortality for the Strigifomes species (Baudvin et al., 1991; de Bruijn, 1994; Taylor, 1994). In agreement with these earlier studies, the high mortality values observed in the current study demonstrate a particularly large impact of road on nocturnal birds of prey populations. Besides the direct impact of vehicle collisions, road traffic may promote long-term fragmentation of populations by decreasing the occupancy of usual nesting sites (Ramsden, 2003), thereby affecting genetic exchanges (Lodé, 2000; Mikkola, 1983). These effects on top predators that are more vulnerable to modification of population structure (Elias et al., 1998) may affect the population's perpetuity.

The most traffic-affected species was the *T.alba*, with more than twice the mortality calculated for the other two species. This difference may be due to the possible ubiquity and relative abundance of *T.alba* in the area surrounding the surveyed road (Fajardo et al., 1992), or because of some specific behavioural, anatomic and/or physiologic features present in this species, which increases its vulnerability to traffic collisions (Clevenger et al., 2003; Erritzoe et al., 2003; Muntaner & Mayol, 1996). This species does not retain as much body fat ($\approx$ 5% of body mass), which affects the amount of energy stores that accumulate and its tolerance to low temperatures (Hoyas & López, 2002; Martínez & López, 1995; Massemin & Handrich, 1997). These limitations conjugate with high activity periods, when males provide food for females during courtship-feeding (Baudvin et al., 1991; Taylor, 1994), with high energy spent for females during the fledging and post-fledging stages (Taylor, 1994), and with starvation during severe winters, all of which may produce poor body condition (Newton et al., 1991). This results in a decrease in the accuracy and efficiency of behavioural responses to outside stimuli, increasing the probability of road-kill episodes. In fact, studies on the body condition of *T.alba* killed on roads have revealed that adult females that are found killed on the road are significantly lighter than females maintained in captivity (Massemin et al., 1998). Additionally, it generally is accepted that *T.alba* usually fly 2-5m above the ground while hunting (Baudvin, 1986), a height which increases its probability of colliding with vehicles travelling on the road.

Factors that determine road casualties

In a general way, the models developed by means of BLR and ENFA exhibit satisfactory accuracy when estimating the probability of fatality occurrence and identifying the explanatory variables that influence this probability. Among the three species, two selected BLR models fit data better than ENFA models did. The use of ENFA in modelling road-fatalities would be useful in generating unbiased occurrence estimates, but one problem that can happen is associated with the spatial structure of data. Biomapper® software does not accept constant, nearly-boolean or overly-fragmented variable maps (Hirzel, 2004). Variable maps that behave in this way must be excluded, left out of the process variables that potentially explain a good percentage of the data. Among the eight variables excluded for this reason, two (fences types and water body types) are included in the group of variables that comprise the models developed using BLR. Consequently, it seems to make more sense to use the BLR models to understand what factors influence fatality incidence.

T.alba

T.alba is a species associated with open land habitats, mainly with cereal cultures (Lourenço et al., 2002; Mikkola, 1983), a characteristic that may explain why fatalities seem to be negatively correlated with the presence of trees (i.e. pine tree culture and tree density) and nearby urban areas.

The typical prey of this species consists of small mammals (i.e. voles, shrews) that tend to occupy the grassland areas undisturbed by agriculture, as well as nearby storm drains and watersheds (Bourquin, 1983; Fajardo et al., 1992; Mikkola, 1983; Van Der Reest, 1992). Consequently, the presence of these structures by the road-side makes the area near the road a great hunting area, suggesting that individuals are attracted there by the availability of food (Meunier et al., 2000; Ramsden, 2003). Permanent and temporary small water bodies also can attract small mammals, especially by having grass vegetation on its edges. The presence of water near but not immediately next to roads may offer an alternative prey-source to road side vegetation, which might reduce hunting over the road itself and, hence, road casualties, a hypothesis supported by the BLR model.

According to Mikkola (1983), *T.alba* may use the still-hunting technique, besides flight-hunting technique to capture their prey. By this technique, individuals spend considerable time perched quietly at some elevated viewpoint, searching for prey, departing only to make the capture. This is supported by the positive correlations between fatalities and nearby fences, and between fatalities and the distance to trees, again identified in the BLR model. In areas where trees and shrubs difficult the flight-hunting technique individuals may perch on a tree or fence post nearer the road, and collide with vehicles when in flight to capture prey.

Both the BLR and ENFA models found mean altitude to have a negative correlation with road-kill occurrence; the greater the altitude, the less the incidence of fatality. This might be explained by the species' difficulty with thermoregulation at high altitudes (i.e. most adverse climatic conditions) and by the inconstancy of prey populations higher up (Hagemeijer & Blair, 1997; Hoyas & López, 2002; Mikkola, 1983).

S.aluco

This species, in contrast to *T.alba*, seems to depend upon dense woods of holm and cork trees and well-structured montado habitats (Elias et al., 1998; Lourenço et al., 2004; Lourenço et al., 2002; Mikkola, 1983), supporting the positive association found between the occurrence of fatalities and the presence of montado habitats, pine cultures and nearby tree density. *S.aluco* use the old oak and cork trees for their nests and to optimize their view of the ground, facilitating both their search for and capture of prey (Cramp, 1992; Hagemeijer & Blair, 1997; Mikkola, 1983; Ramsden, 2003; Taylor, 1994). We expected, in our study, to see similar results, not only for roadside trees, but also for other tall structures. However, the BLR model did not corroborate this hypothesis; negative association was identified between fatalities and either wire or post density near roads. As these structures usually are placed along the stretch of road, areas with a high density of trees may make it difficult for *S.aluco* to fly from whatever perch they have to access their prey, merely because of these additional obstacles in their way; but this is just a hypothesis. Note that this feature identified a significant negative correlation with tree density near roads ($r = -0,349$; $p<0,01$).

As the food items for this species are the same as for *T.alba*, the presence of water bodies near roads offers the same alternative food source to road side vegetation, potentially explaining the decreased incidence of fatalities when a water body is nearby.

A.noctua

Both model methods identify, for *A.noctua*, the ***minimum distance to localities*** variable as significant in determining the probability of fatalities; the greater the distance, the lower the probability. This is in agreement with what we actually know about this bird, which seems to be a species closely associated with human-altered habitats, where the most important requirements are food availability (i.e. small mammals and insects) and some hollow trees to place nests (Árias, 1994; Exo, 1992; Tomé et al., 2004). This also can explain the relationship between road fatalities and olive orchards observed in the ENFA model. Olive orchards, besides being rich in hollow trees (one single olive tree can provide up to six breeding sites) also harbour grass patches around the base of the trunks, where insects are present (Fajardo et al., 1998).

Besides occupying human-altered habitats, they tend to avoid woods with high vegetation density (Cramp, 1992; Fajardo et al., 1998; Hagemeijer & Blair, 1997; Lourenço et al., 2004; Mikkola, 1983; Tucker et al., 1994). Hernandez (1988) identified the lack of trees along the road as a factor responsible for increasing road casualties in this species. They trend to prefer more open areas and use the still-hunting technique (Cramp, 1992; Elias et al., 1998), which is consistent with the positive correlation between mortalities and cereal crops, and the negative effects of tree density and the distance between trees on either side of the road. Conversely, fences along the road are associated with lower fatality rates, though the reasons for this are unclear and warrant further study. Perhaps, in the present case, the fences along the road have associated shrubs that make the fences inadequate for perching, so that these birds use the road as an alternative (Hodson, 1962), thereby increasing the number of fatalities.

Temporary blindness of *A.noctua* individuals by car headlights is known to be an important variable that is responsible for a significant number of causalities (Hernandez, 1988). Road-side reflectors would be expected to increase this phenomenon and the resultant deaths, as the BLR model predicts.

Variable slope diversity is significantly correlated with four of the variables included in the model (but with a correlation coefficient lower than 0,07): Fences (r =0,547; p<0,01); reflectors (r=0,340; p<0,01); type of body of water (r =0,202; p<0,01) and distance between trees on two sides of the road (r =0,255; p<0,01). What may explain the inclusion of this variable in the model is the model selection method itself, rather than it having some direct influence on *A.noctua* fatalities.

As with the other two species, bodies of water also correlate negatively with the incidence of road casualties. The explanation for this may be the same as for *T.alba* and *S.aluco*, but this warrants further study to test this hypothesis in the three species.

Identification of fatality hotspots

Many methods have been utilized to identify the locations of fatality hotspots. Traditionally, the road is divided into segments of varying length and predictive models are developed using the information (i.e. fatality numbers and possible explanatory variables) obtained from each one (Finder et al., 1999; Malo et al., 2004; Ramp et al., 2005; Saeki & Macdonald, 2004). Others approaches being proposed include modelling fatality data based upon point locations (Clevenger et al., 2003) and performing *Malo's method* to fatality counts by segment (Malo et al., 2004). However, most of these methods convert presence-only data to binary data (i.e. presence vs. absence), obtaining absences from segments with no fatalities recorded (Ramp et al., 2005). Misclassification of absence data can result, due to the constant traffic that could displace or remove carcasses between surveys. To circumvent this problem, kernel density estimation has been suggested as an appropriate approach when presence data only exist (Ramp et al., 2005).

In the present study, five hotspot identification methods were tested. One predictive model was developed using BLR for 500m segments. *Malo's method* was used to determine expected fatality counts in 500m segments. One distance-based hotspot identification method (NNHC) was use to identify fatality locations closer to each other than one would expect randomly. Kernel estimation density was applied to fatality locations. A presence-only modelling method (ENFA) was used for 500m segments. The ability of each one of these methods to identify hotspot locations varied considerably. LBR and ENFA modelling performed more weakly when the HLvsKP ratio was analyzed. This demonstrates the quantity of data that are lost in these two models during the conversion from quantitative into presence/absence data (i.e. binary data) or into presence-only data, losses which are significant in the localization of hotspots. Versus all the other methods, *Malo's method* showed the greatest ability to detect the most dense hotspot locations. When applied to the surveyed road, it accounted for the smallest effort if minimization measures are applied (i.e. short hotspot length) to prevent a relatively greater number of kills (see HLvsKP ratio).

As stated in the Results section, the *Malo's method* and NNHC methods do not allow for understanding the clustering of fatalities at all scales, merely identifying first-order clusters but not the relationships between them, or clusters at different scales. This understanding only is achieved using the kernel density estimation, when the selection of the marked percentile reflects the target scale needed for understanding the clustering phenomena. This feature of the kernel density method also allows for regulation of the extent to which minimization measures will be enacted at each hotspot, based upon the amount of effort and resources available. Furthermore, in accordance with the HLvsKP ratio, the kernel method also displays a good ability to detect dense hotspot locations.

Mitigation measures

It is widely accepted that strigiformes are attracted to roads and their surroundings, because of environmental conditions, and required energy expenditures in the pursuit of food (Baudvin et al., 1991; Bourquin, 1983; de Bruijn, 1994; Fajardo et al., 1992; Hernandez, 1988; Taylor, 1989, , 1994). Besides the relatively good habitat provided adjacent to most roads, hunting issues seem to be the principal cause for road casualties in these species. Consequently, mitigation measures must focus on these issues.

Altering the road proximity to some habitat features in accordance with hunting behaviours could decrease road casualties. It seems obvious that reducing the area of undisturbed grassland will decrease the number of small mammals near roads, reducing the number of small mammals killed by traffic (Fajardo et al., 1992). This also should reduce the tendency of strigiformes to use these areas for hunting. However, care must be taken when the target road crosses the distribution area for some species that depends on grassland habitats, as was the case with the surveyed road which crosses the Cabrera's vole (*Microtus cabrerae*; conservation status = rare, IUCN) distribution area.

This species may depend upon road-side grassland areas to maintain its populations and the connectivity between them during dryer summers (Pita et al., 2006). Also, certain measures, like planting short bushes, should decrease the visibility and accessibility of small mammals (Baudvin et al., 1991).

Another way to reduce the interest of these species in road-side areas would be to promote better hunting grounds a short distance away from the road (i.e. not at the road-side), for example by creating small water bodies (temporary or permanent) that can support a grassland habitat for most of the year, thereby permitting small mammal populations to live there, and providing Strigiforme species with a safer place to hunt. Perches, like fences, posts or other similar structures could be placed near these water bodies to attract predators that use the still-hunting technique (Hernandez, 1988).

Contrary to Hernandez' (1988) suggestion that *A.noctua* suffer less road mortality when high perches (>2m) are available, in this study we found that high perches (i.e. trees) near the road tends to increase mortality. If possible, in both *T.alba* and *A.noctua* hotspots, trees could be removed or transplanted from the road side, reducing the number of perches available close to the road. Also, fences should be removed, but only in *T.alba* fatality hotspots, because the effects of fences are not completely understood in the case of *A.noctua*.

Conclusions

To mitigate the adverse influence of roads on populations of Strigiforme species, the first critical step is to accurately identify the location of fatality hotspots. Our results indicate that kernel density estimation is the most versatile method for this purpose. This is true when fatality location data exist, but when no data exist, predictive models are able to provide a good approximation of hotspot locations. In model construction, priority should be given to regression methods that use quantitative data, rather than binary data.

After identification of fatality hotspots, there is a need to understand the factors that influence this clustering, thereby to identify potential minimization strategies that should be applied to these target areas. In these situations, the development of predictive models using BLR enables the identification of deterministic variables that influence road-mortality.

The variables identified as determinants of road fatalities among Strigiforme species generally were associated with the existence of good habitat conditions in the areas crossed by the roads, and with the existence of specific conditions that facilitate hunting behaviour near roads.

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Considerações finais

O atropelamento é actualmente considerado uma importante causa da mortalidade em Strigiformes (Baudvin et al., 1991; de Bruijn, 1994; Taylor, 1994), situação que se reflecte no índice de mortalidade calculado para as espécies alvo deste estudo. A mortalidade global foi de 0,94 atropelos/km/ano, para a qual contribuiu o elevado número de atropelos registado para *T.alba* de 0,49 atropelos/km/ano atingindo aproximadamente o dobro da mortalidade de cada uma das restantes espécies. Tanto as características anatómicas, comportamentais e fisiológicas de *T.alba*, como a sua ubiquidade em áreas próximas da estrada podem estar na origem desta elevada taxa de mortalidade. Pelo facto de *S.aluco* e *A.Noctua* serem espécies menos ecléticas no que concerne ás condições óptimas do habitat, que no presente caso se restringem a uma porção da área circundante à totalidade da estrada, obteve-se um índice de mortalidade inferior para estas espécies relativamente à anterior.

A mortalidade destas espécies parece estar associada à existência de boas condições de habitat nas áreas atravessadas pela estrada, e da ocorrência de determinadas condições que promovem um elevado número de episódios de caça junto da mesma. Enquanto que *S.aluco* parece estar associada a habitats com predominância de árvores como o montado, as restantes espécies tendem a evitar este tipo de habitats. *A.noctua* está principalmente associado aos habitats de origem atropogénica que surgem perto das localidades, e *T.alba* tende a ocorrer em habitats abertos como pseudo espetes cerealíferas de baixa altitude. Todas as Strigiformes estudadas têm como presas espécies que ocorrem em zonas de elevada densidade de gramíneas, como micro mamíferos e insectos (Bourquin, 1983; Fajardo et al., 1992; Mikkola, 1983; Van Der Reest, 1992). A presença destas estruturas nas bermas da estrada e a respectiva abundância em presas torna-a um óptimo local de caça para estes predadores (Meunier et al., 2000; Ramsden, 2003). A existência de sulcos de drenagem nas bermas e o atravessamento de linhas de água incrementam a presença destes habitats junto da estrada, contribuindo para um aumento da frequência de episódios de caça e consequentemente da mortalidade, nomeadamente em *T.alba*. Por outro lado a ocorrência de massas de água e da vegetação associada às suas margens nas imediações da estrada, que não nas suas bermas, actuam como uma fonte de presas alternativa diminuindo actividade destas espécies sobre via e o número de mortes registadas. Os modelos desenvolvidos também sugeriram que a presença de árvores junto da estrada tende a aumentar a mortalidade em *T.alba* e *A.noctua*, talvez devido ao seu uso como poisos garantindo uma óptima visibilidade sobre a vegetação das bermas, optimizando a busca/obtenção da presas e consequentemente intensificando a actividade de caça nessas áreas. O mesmo efeito parece estar associado à presença de cercas junto da estrada no caso da *T.alba.*

A minimização da mortalidade destas espécies, associada aos atropelamentos, deverá passar pela alteração das características, que na área circundante à via, potenciam a sua utilização como zona de caça. Reduzindo a abundância de gramíneas nas bermas parece obvio que se reduz substancialmente o interesse que estas zonas suscitam nas Strigiformes, no entanto há que ter em atenção o facto de que em algumas situações a persistência de outras espécies poderá depender da existência dessa vegetação. Outra forma de reduzir o interesse nas bermas pode ser a criação de *zonas de caça* alternativas nas imediações da estrada, no entanto fora da área das bermas. A criação destas zonas poderá incluir a instalação de pequenas massas de água (i.e. charcos temporários ou permanentes) que permitirão a fixação de populações de micro mamíferos na suas margens, resultando uma área com igual abundância de presas mas com menor riscos de atropelamento do que as bermas. Por último a remoção das árvores na proximidade da estrada para os pontos negros identificados para a *T.alba* e *A.noctua.*

A distribuição dos atropelos não ocorre aleatoriamente ao longo da estrada, tendo sido identificados diversos pontos negros de mortalidade para as diferentes espécies. Dos modelos de identificação de pontos negros testados, apesar da dificuldade de comparação entre eles, inerente as diferenças nas suas abordagens, a Regressão Logística e a modelação mediante Ecological Niche Factor Analysis obtiveram em todos os casos uma performance fraca. O uso da Regressão Logística apenas se justifica quando, na ausência de informação relativa a atropelos, é necessário obter uma aproximação da localização dos hotpots para as referidas espécies. Dos restantes métodos, o descrito por Malo (2004) parece obter uma melhor performance, no entanto quando se objectiva a implementação de medidas minimizadores, o Kernel deverá ser o modelo preferido devido a sua versatilidade.

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